First Results from Suzaku

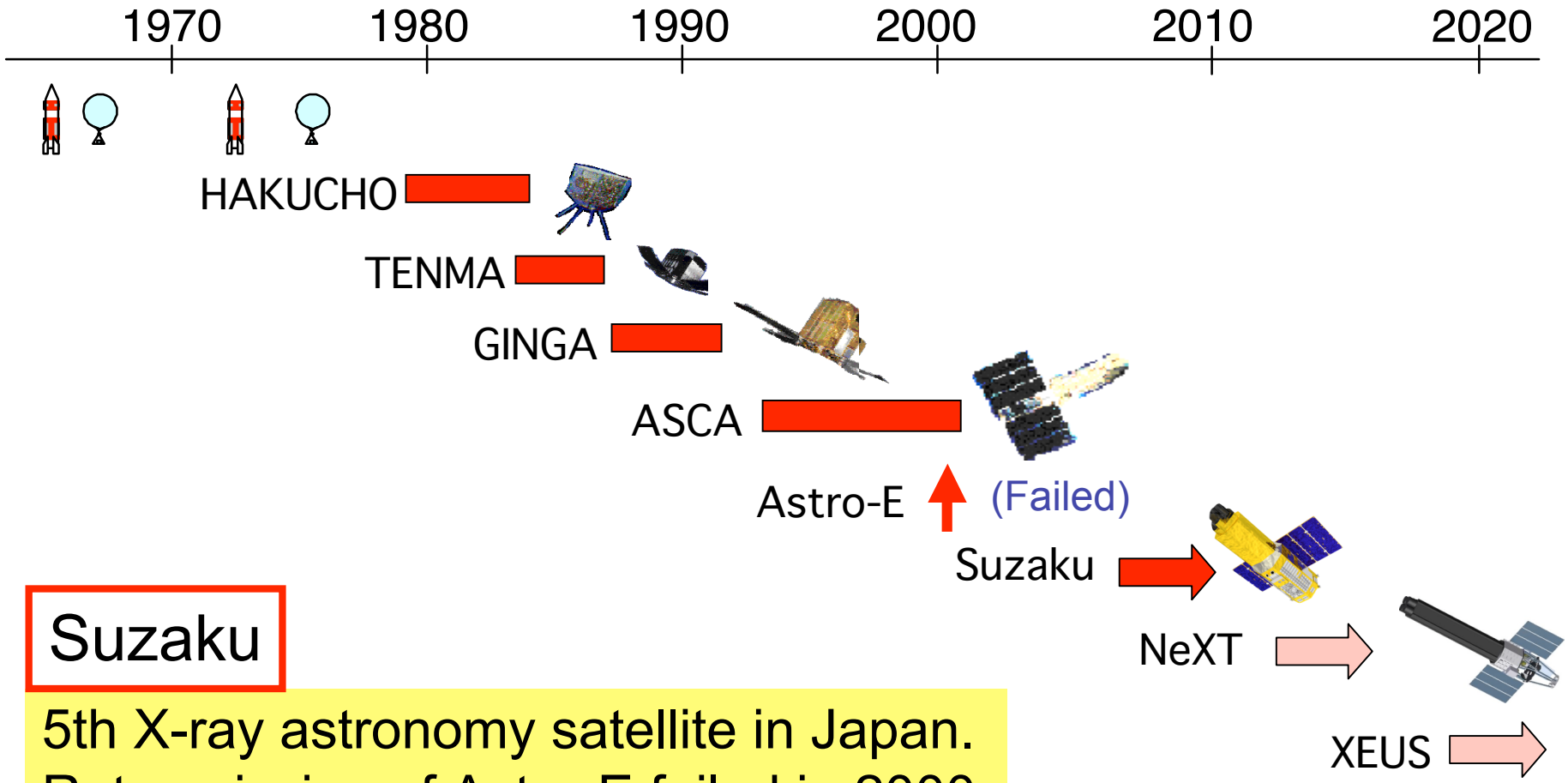
Tadayasu Dotani
Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency

Note
Many of the slides of the initial results are omitted because they are still preliminary.

Outline of the lecture

- Suzaku and X-ray telescope/detector
  - X-ray telescope (XRT)
  - X-ray Micro-calorimeter (XRS)
  - X-ray CCD camera (XIS)
  - Hard X-ray detector (HXD)
- Initial operation and first light
  - Loss of XRS
- Initial results
- Summary and miscellaneous information

History of the X-ray Astronomy Satellites in Japan



Suzaku

5th X-ray astronomy satellite in Japan.
Retry mission of Astro-E failed in 2000.

Suzaku (Astro-E2)

Astro-E2 in ISAS clean room

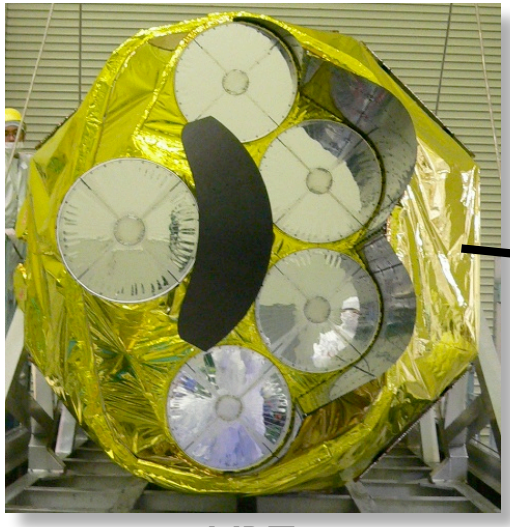
Recovery mission of Astro-E

Weight: 1700kg
Power: 1400W

Launch: July 10, 2005
Orbit: near-earth circular orbit (altitude 570km)
Developed under Japan/US collaboration.

Objective

Wide-band, high spectral resolution observations of X-ray sources.

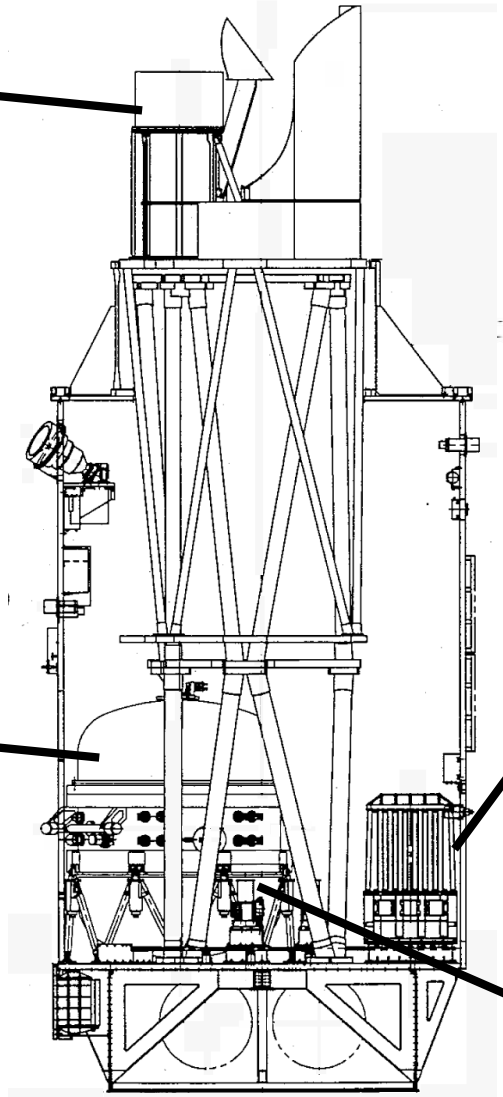


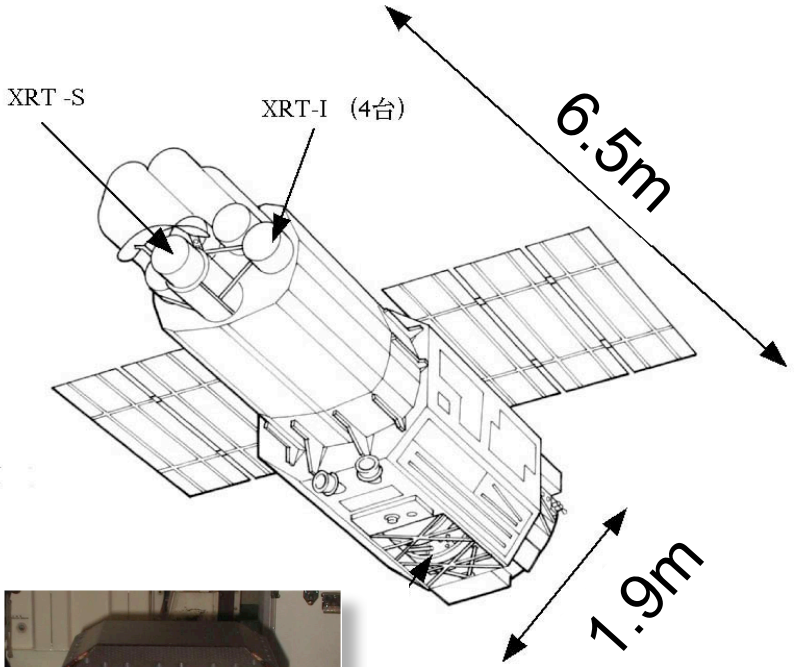
X-ray mirrors

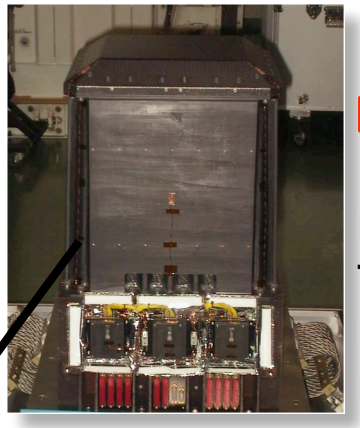
XRT

NASA/GSFC-Nagoya-

ISAS/JAXA







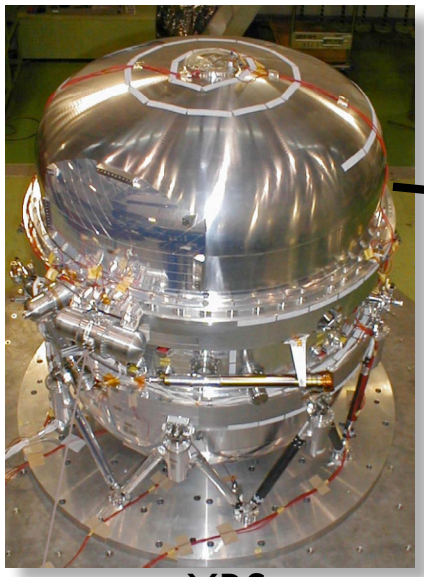
Hard X-ray detector

HXD

Tokyo-ISAS/JAXA-

Riken-Saitama-

HIroshima-Kanazawa-...



XRS

NASA/GSFC-Wisconsin

-ISAS/JAXA-TMU

X-ray micro calorimeter

X-ray CCD camera

(4 sets)

XIS

MIT-Kyoto-Osaka -

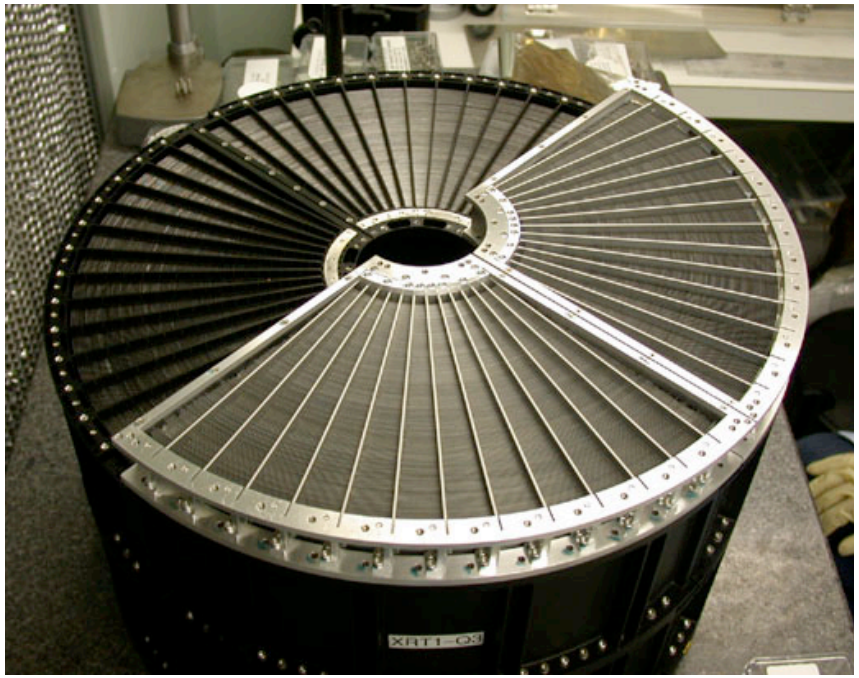
ISAS/JAXA-.....

Suzaku telescopes/detector

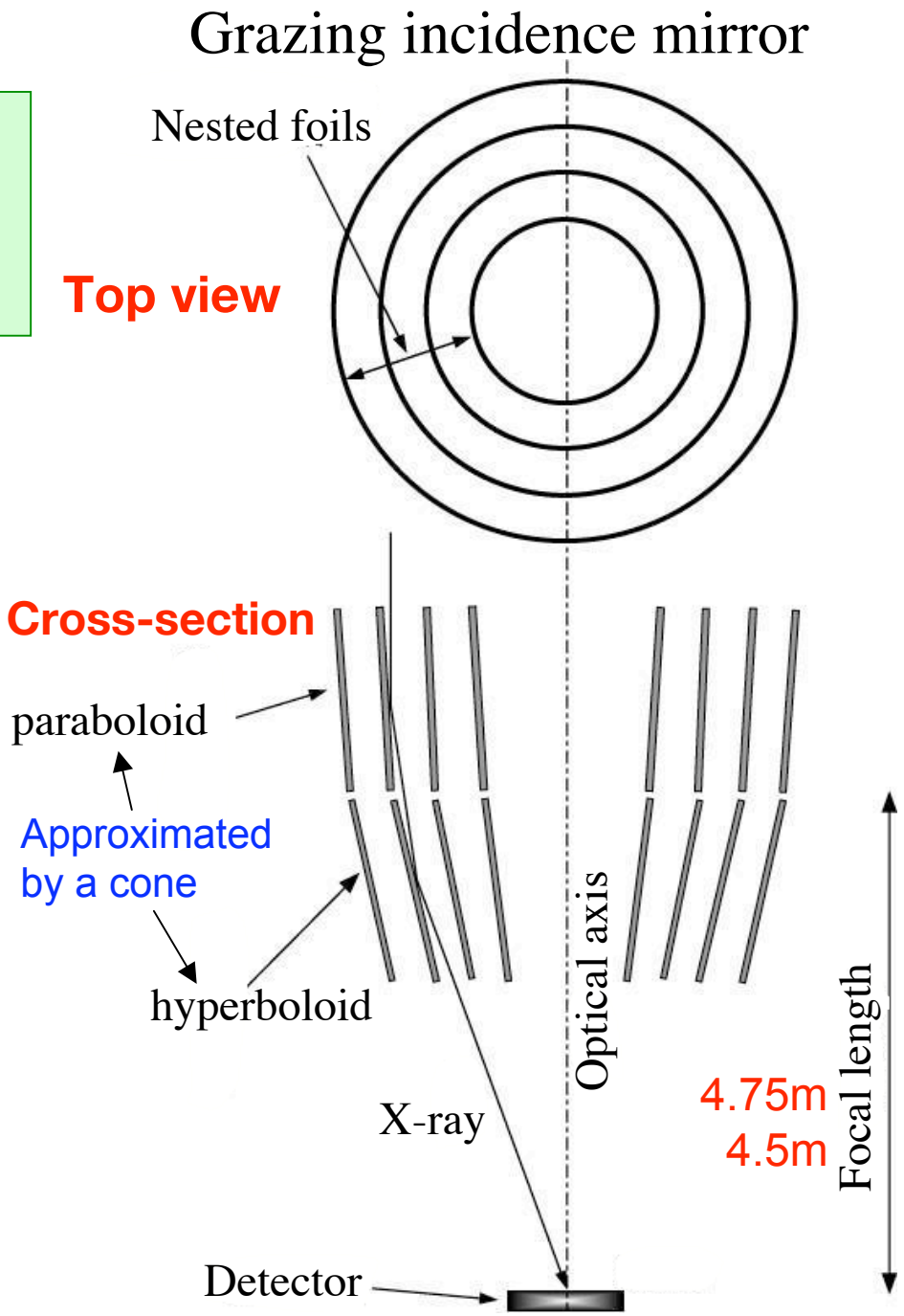
Instruments	XRT-S+XRS	XRT-I+XIS	HXD
Main role	High resolution spectroscopy	Wide-band spectroscopy	
Energy range	0.3-10 keV	0.2-12 keV	10-600 keV
Effective area (cm^2)	150 (@6keV)	1300 (@1.5keV)	160 (@20keV) 260 (@100keV)
FOV	2.9'x2.9'	18'x18'	0.56^ox0.56^o (<80keV) 4.6^ox4.6^o (>100keV)
PSF	~2' (HPD)	~2' (HPD)	
Energy resolution	~7 eV	130eV (@6keV)	3keV (@20keV) 10% (@550keV)
Time resolution	5μs	8ms-8s	61μs
life	2.4-3 yr*	As long as possible	

X-ray telescope (XRT)

40 cm

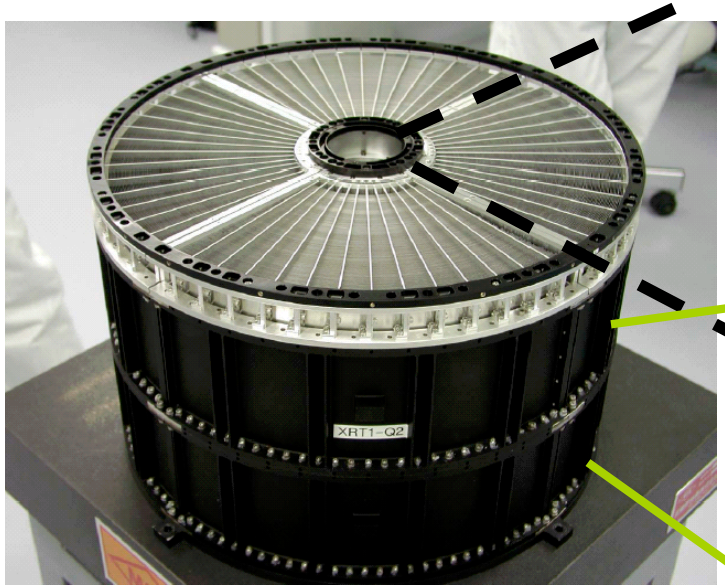


Installing the pre-collimator

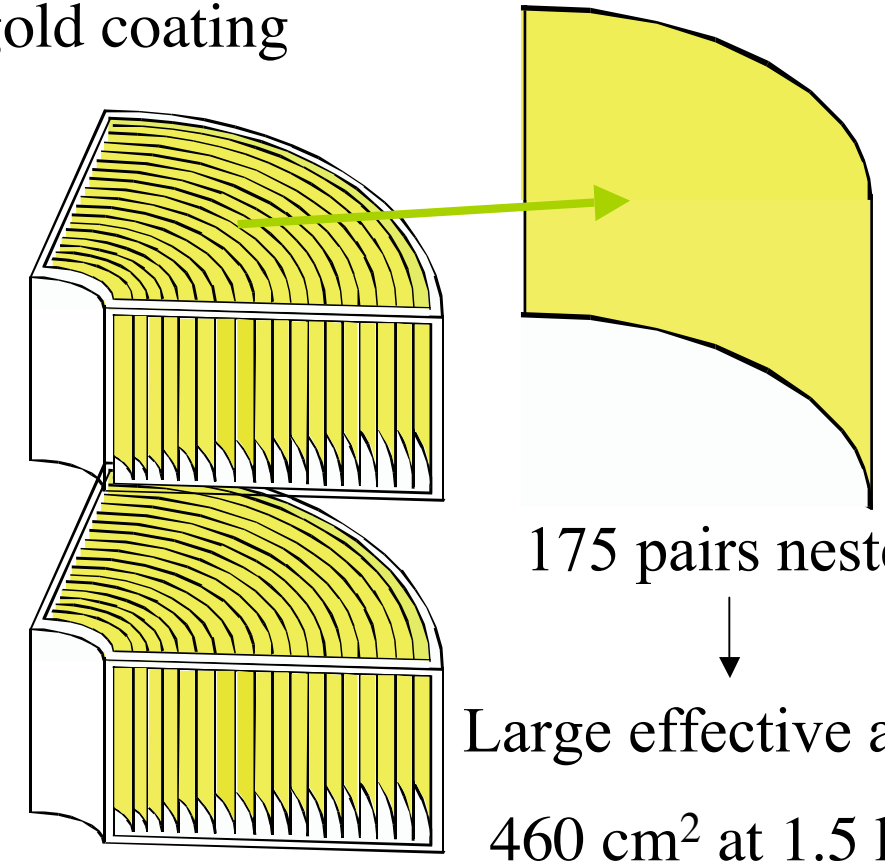


Structure of the Mirror

Fabricated in unit of
1/4 sectors (quadrant)



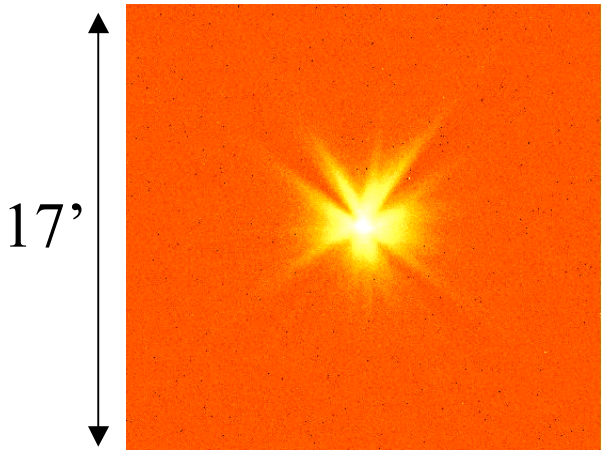
Aluminum foil with
gold coating



175 pairs nested

Large effective area

460 cm^2 at 1.5 keV

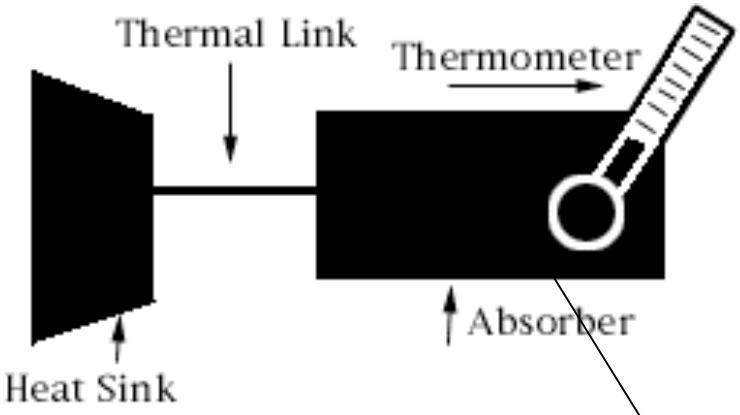


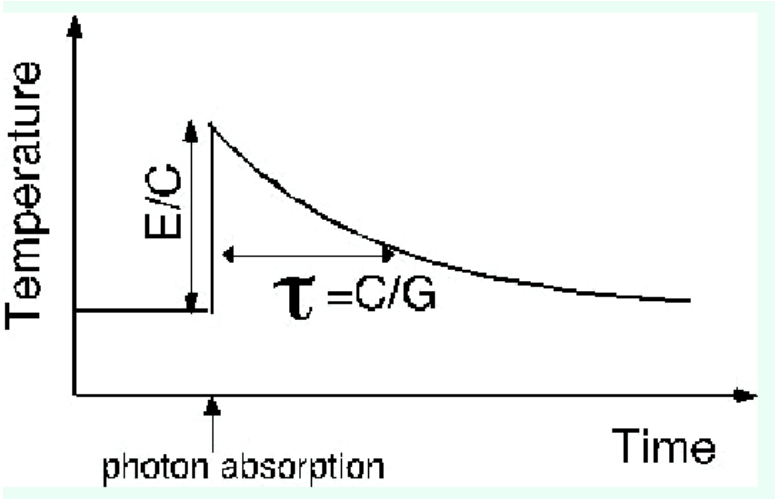
Ground calibration image
(point source)

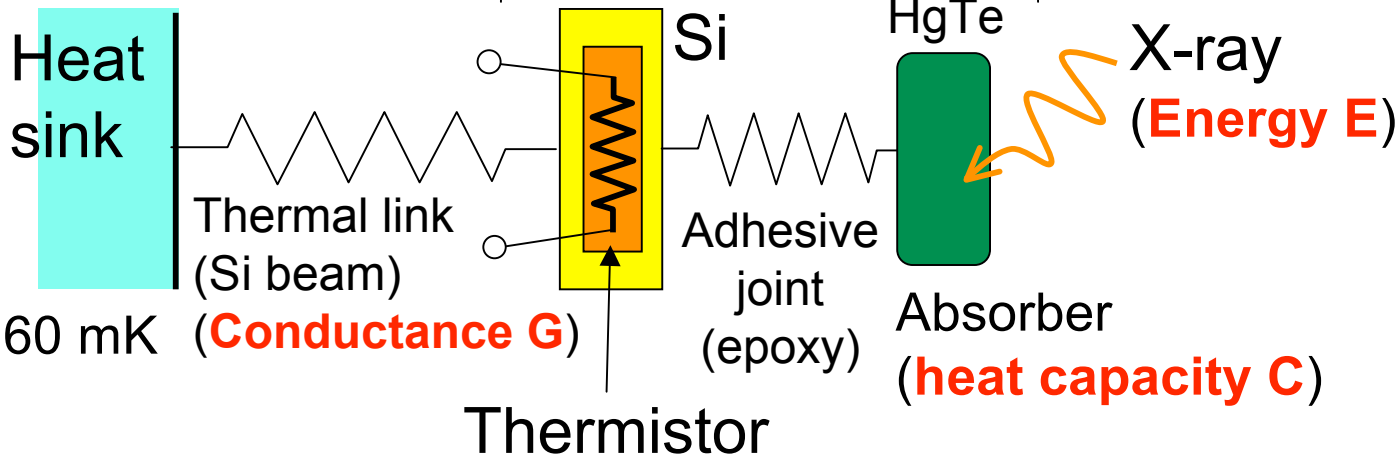
1.9 arcmin (HPD)

Developed by GSFC,
Nagoya Univ, ISAS/JAXA.

Principle of X-ray Micro-calorimeter (XRS: X-Ray Spectrometer)







Typical parameters of XRS

Thermal parameters of XRS

Heat Capacity: C = 0.18 pJ/K
Conductance: G = 60 pW/K
Heat sink temp: T = 60 mK

$$\tau \approx C/G \approx 3\text{ms}$$

$$\Delta T \approx \frac{E}{C} \approx 0.9\left(\frac{E}{1\text{keV}}\right)\text{mK}$$

Energy resolution

Thermal energy of a pixel: CT
Typical energy of a phonon: kT

Typical number of phonon = C/k

$$\Delta E \approx \sqrt{\frac{C}{k}} \cdot kT = \sqrt{kT^2 C}$$

Theoretical limit

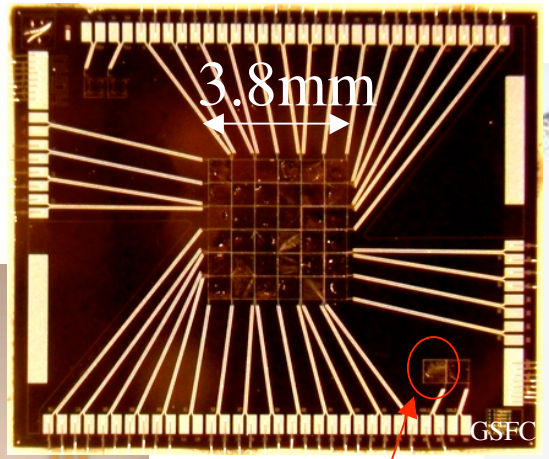
$$\Delta E_{\text{FWHM}} \approx 4\text{eV}$$

XRS Sensor

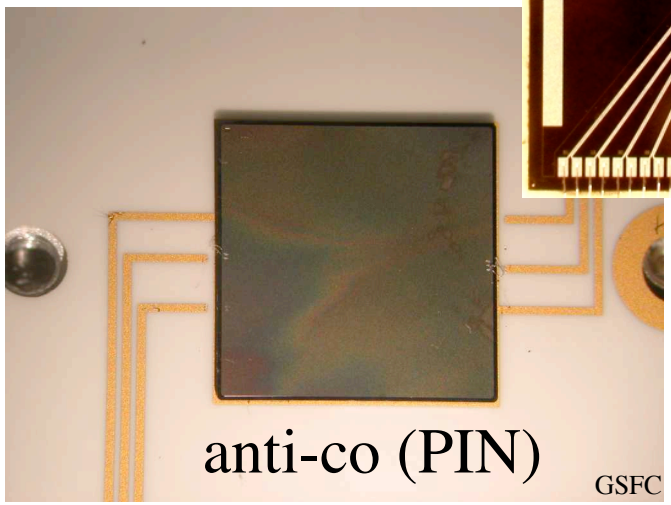
- 6x6 2D array, 3.8mm x 3.8mm (2.9'x2.9' FOV)
- 30 active pixels + 1 dedicated calibration pixel
- Operated at 60mK
- $\Delta E \sim 6eV$

Developed by GSFC, Wisconsin Univ, ISAS/JAXA, TMU, etc.

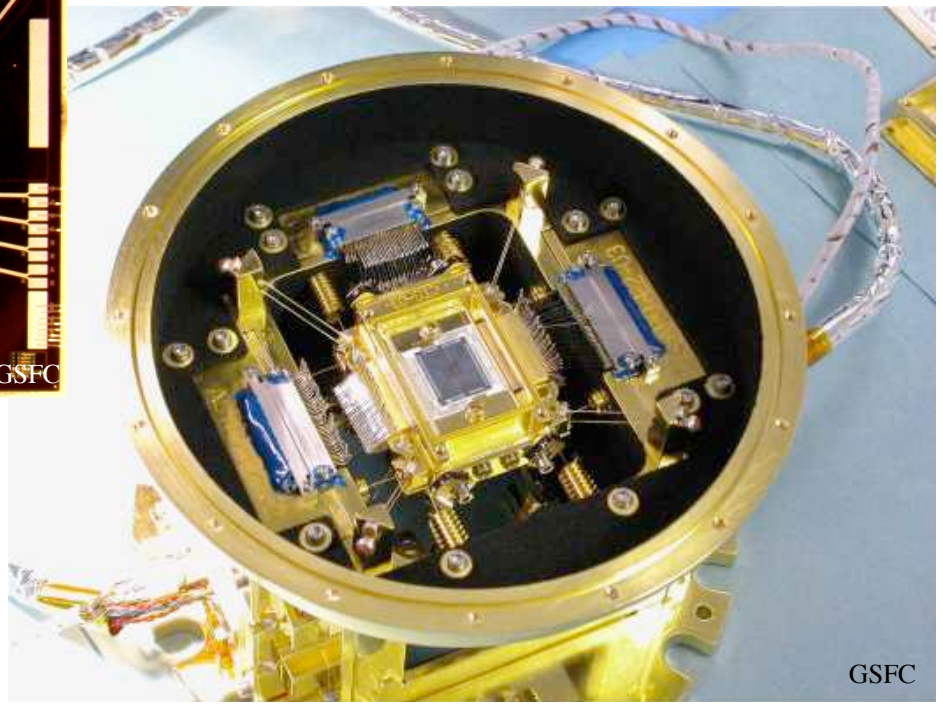
calorimeter array



cal pix

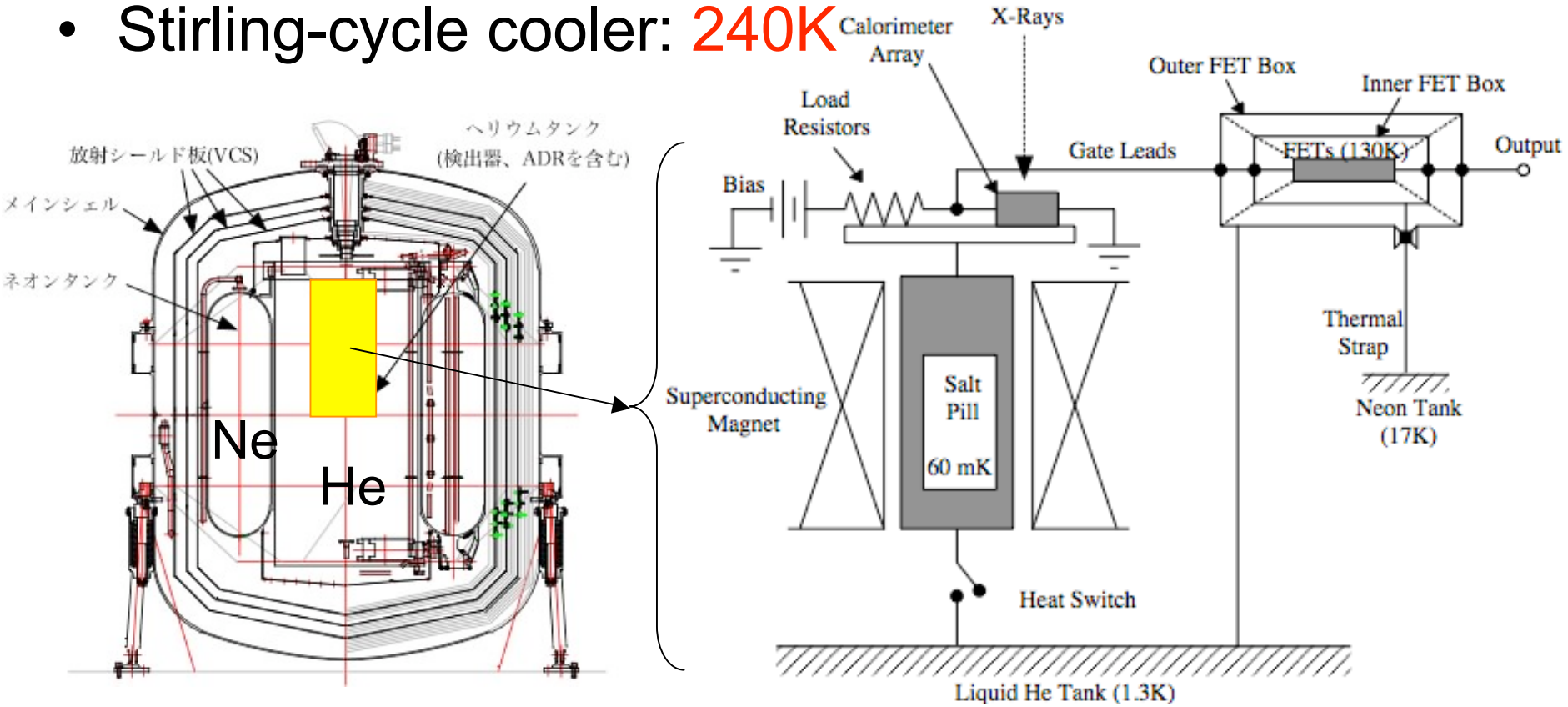


sensor housing (FEA)

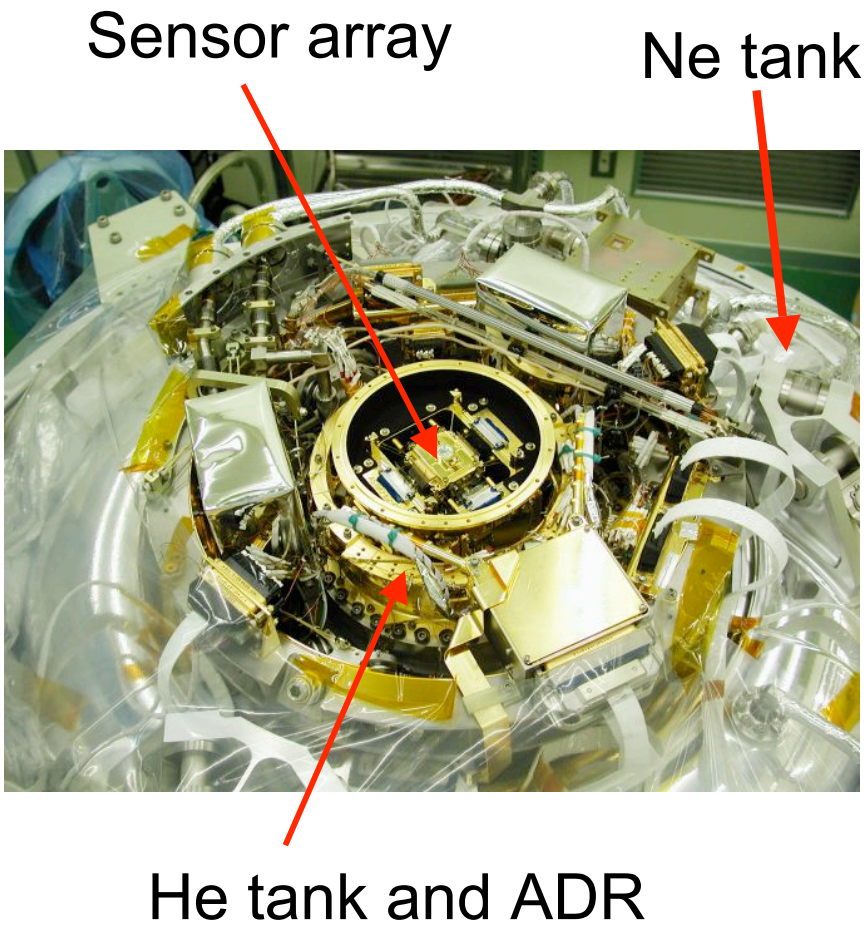


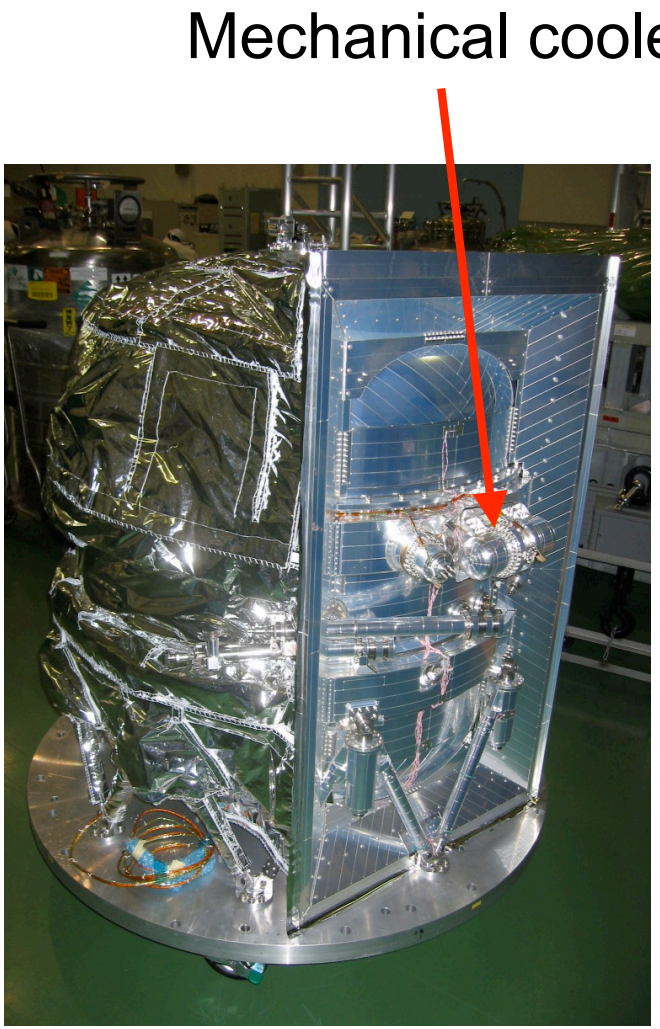
Cryogenics

- ADR: 60mK
- superfluid liquid helium: 1.3K, 30 litters
- solid neon: 17K, 120 litters (~200kg)
- Stirling-cycle cooler: 240K



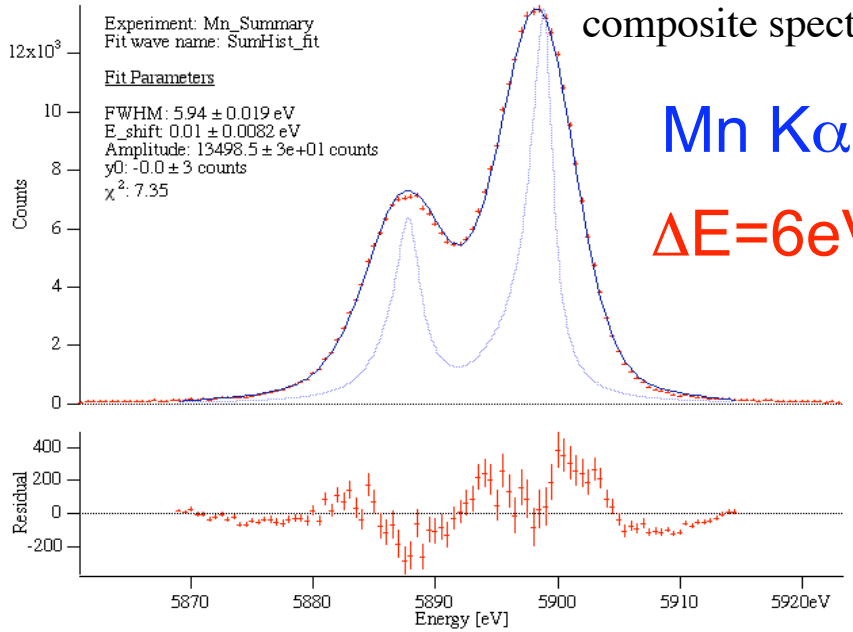
Top/Outside view of XRS





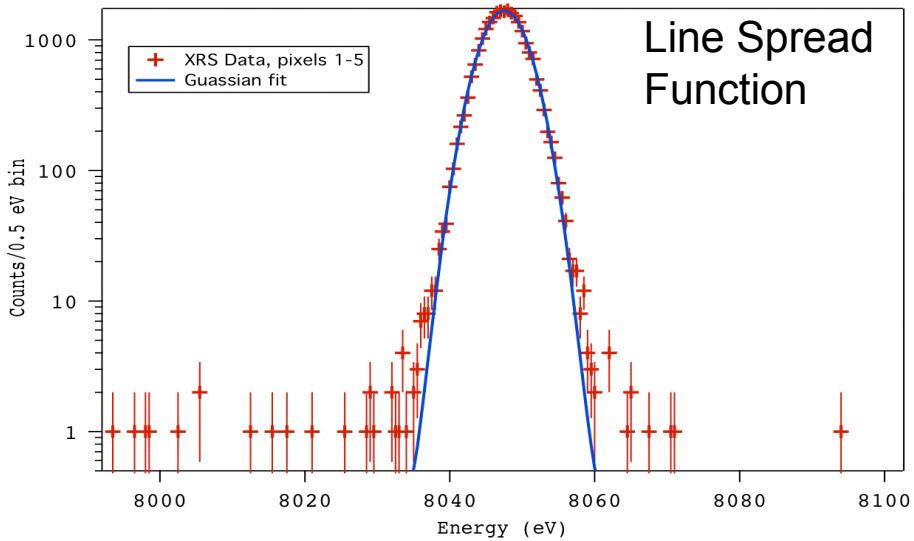
Ground calibration data

composite spectrum of Mn kα

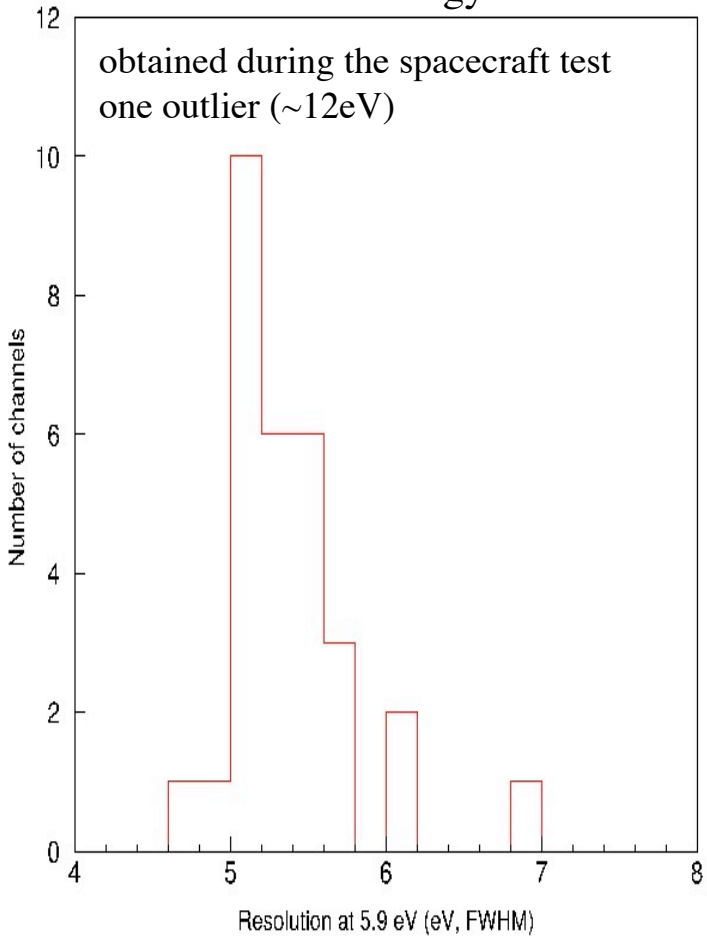


Mn Kα

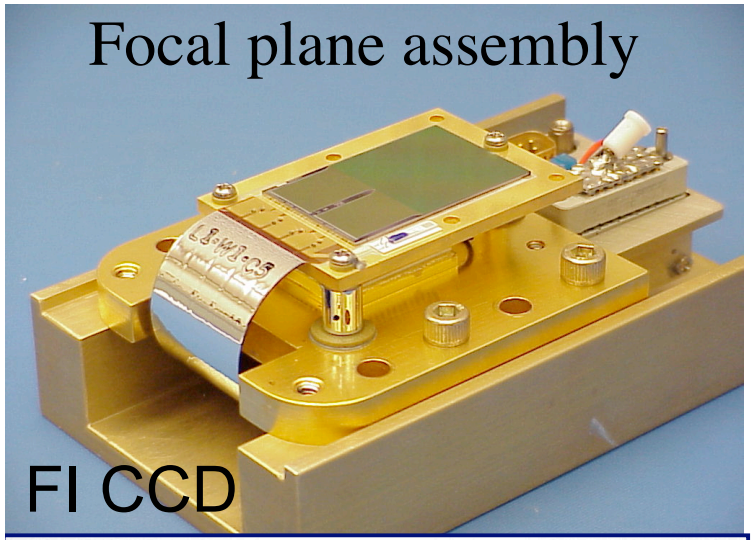
ΔE=6eV

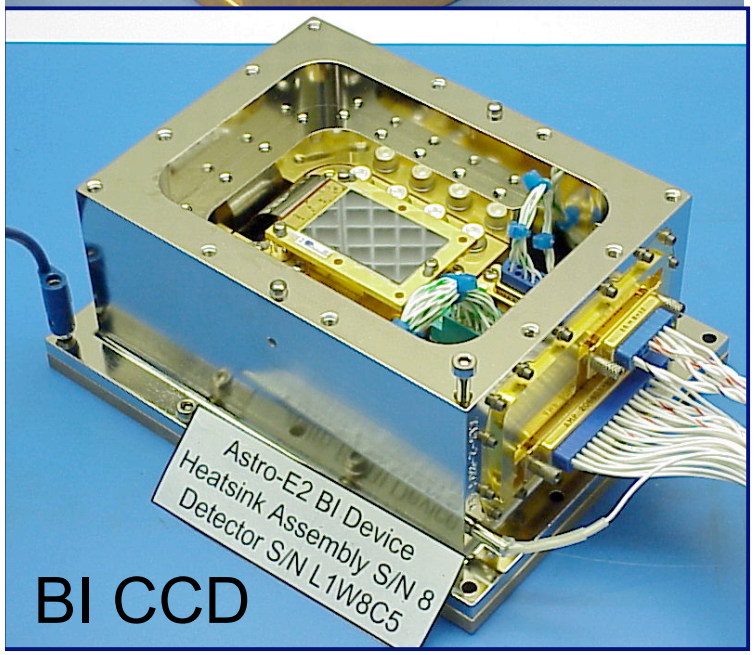


distribution of energy resolution



X-ray CCD camera (XIS)





4 CCD camera

- 3 set of FI (front-side illuminated) CCD
- 1 set of BI (back-side illuminated) CCD

Architecture	frame-transfer
Clock	3-phase
Pixel size	24x24μm
Format	1024x1026 (imaging area)
Depletion layer	70μm (FI)
Readout time	8 sec (nominal)
Oper. Temp	−90C
FOV	18'x18'

Developed by MIT, Kyoto Univ, Osaka Univ, ISAS/JAXA, etc.

New technology in BI CCD

Negative oxygen ion at the surface increases the collection efficiency of electrons.

Developed by Univ. of Arizona.

Deadlayer

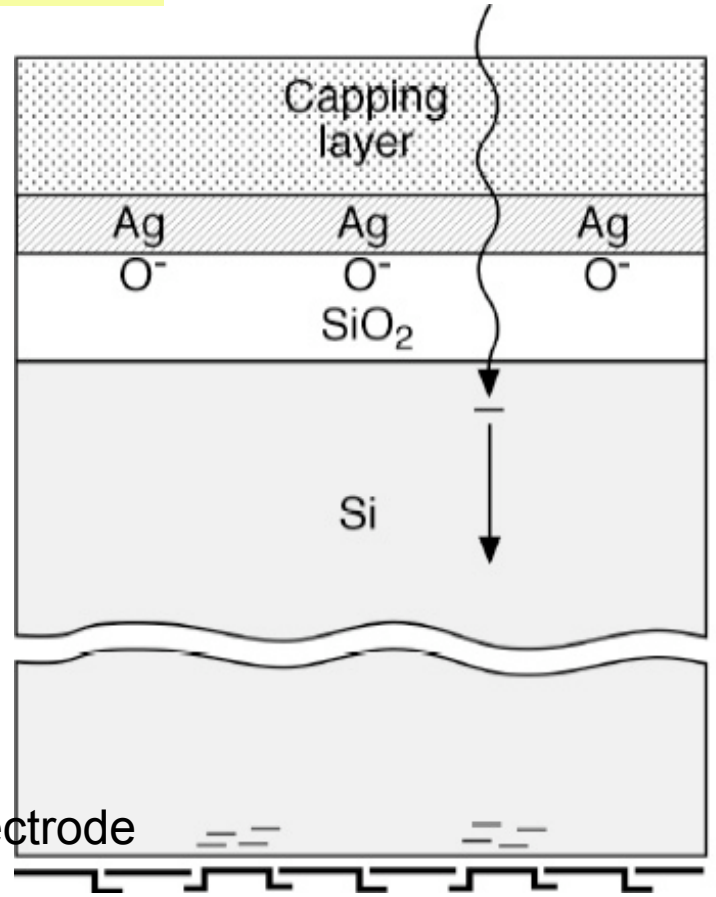
5 nm HfO_2

1 nm Ag

3 nm SiO_2

Sensitive Volume

45 μm Si



Backside

Catalytic charging of O atoms to O^- by Ag

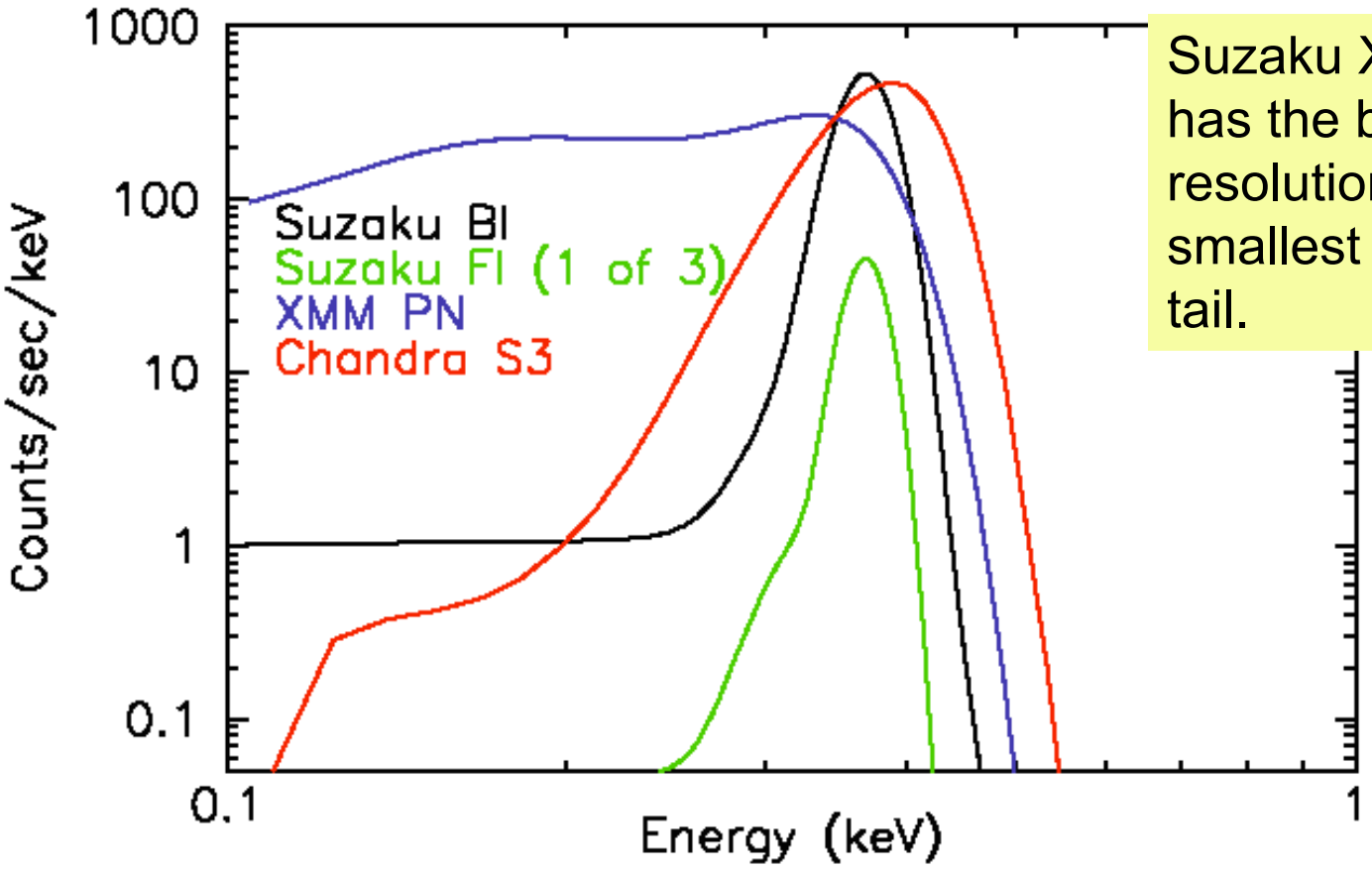
Thinned CCD

Frontside

(Burke, Lesser et al., 2003)

Comparison of the energy resolution

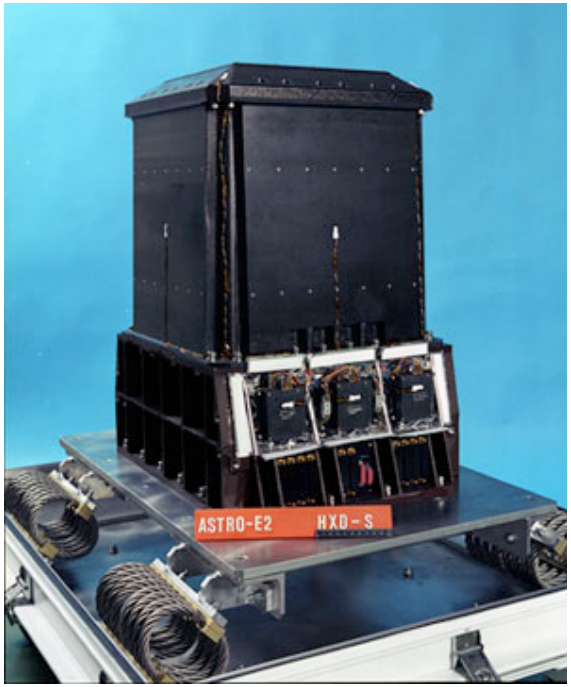
Spectral responses to 0.37 keV X-rays



Suzaku XIS BI ccd has the best energy resolution and the smallest low-energy tail.

Hard X-ray Detector (HXD)

High sensitivity is realized by the development of ultra-low background (rather than big/heavy) detector.



Non-imaging, hybrid detector

- Si PIN diode

  5-80 keV, 34'x34' (FWHM)

- GSO scintillator

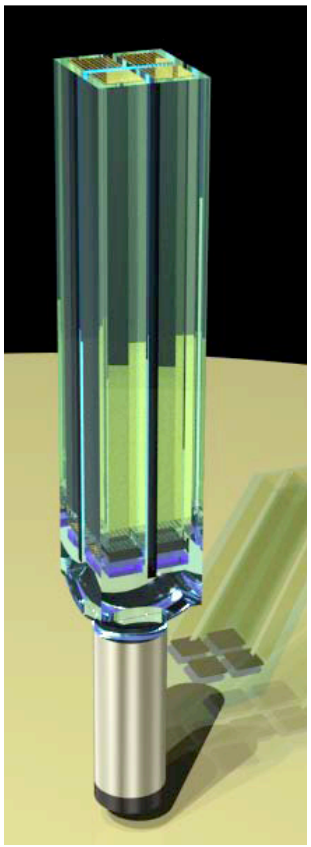
  50-600 keV, 4.5x4.5 deg (FWHM)

- BGO active shield

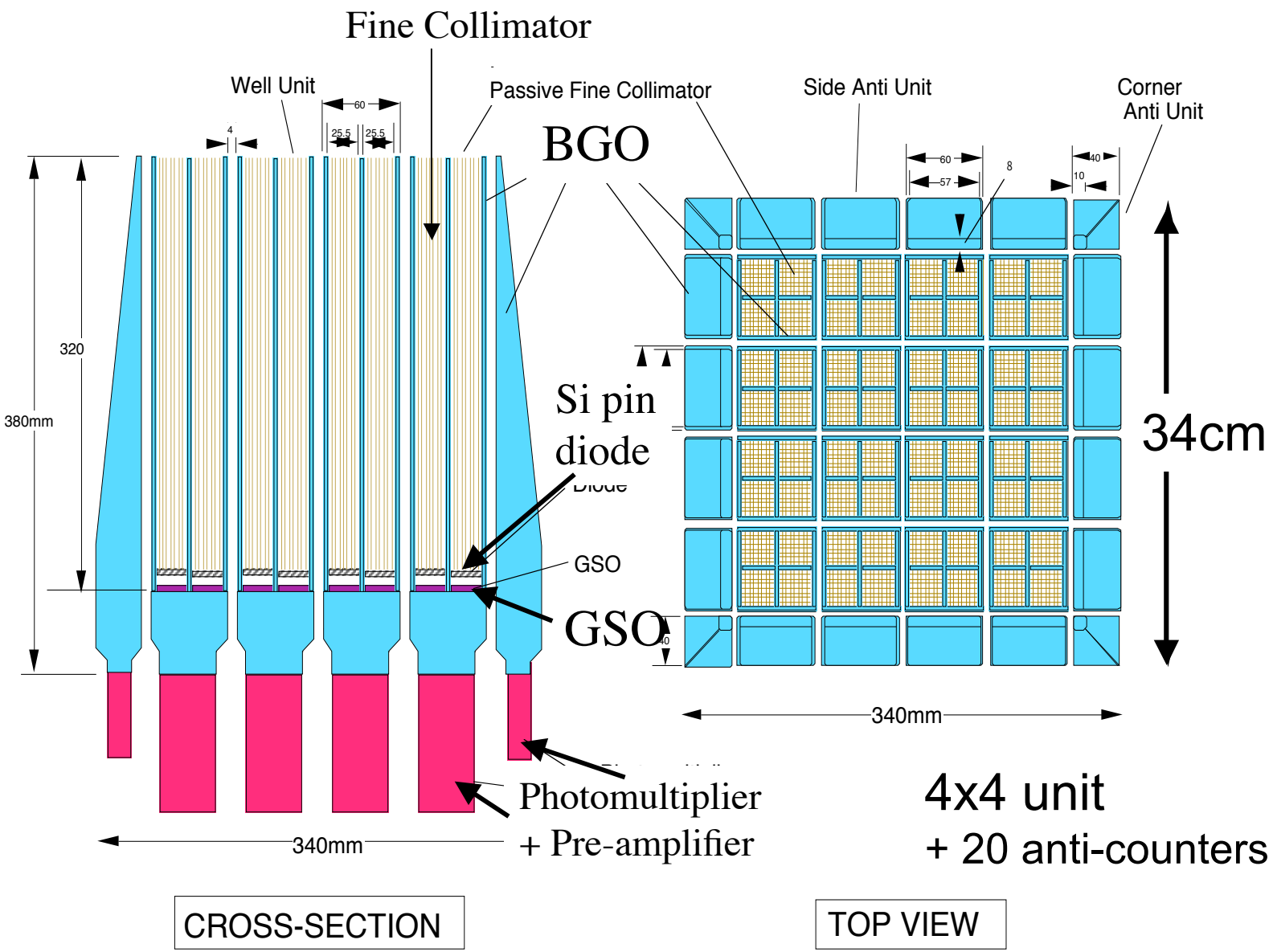
  Well-type (five-sided) shield

Developed by Tokyo Univ, RIKEN, Saitama Univ, Osaka Univ, Hiroshima Univ, Kanazawa Univ, Aoyama Univ, ISAS/JAXA, KEK, SLAC, etc.

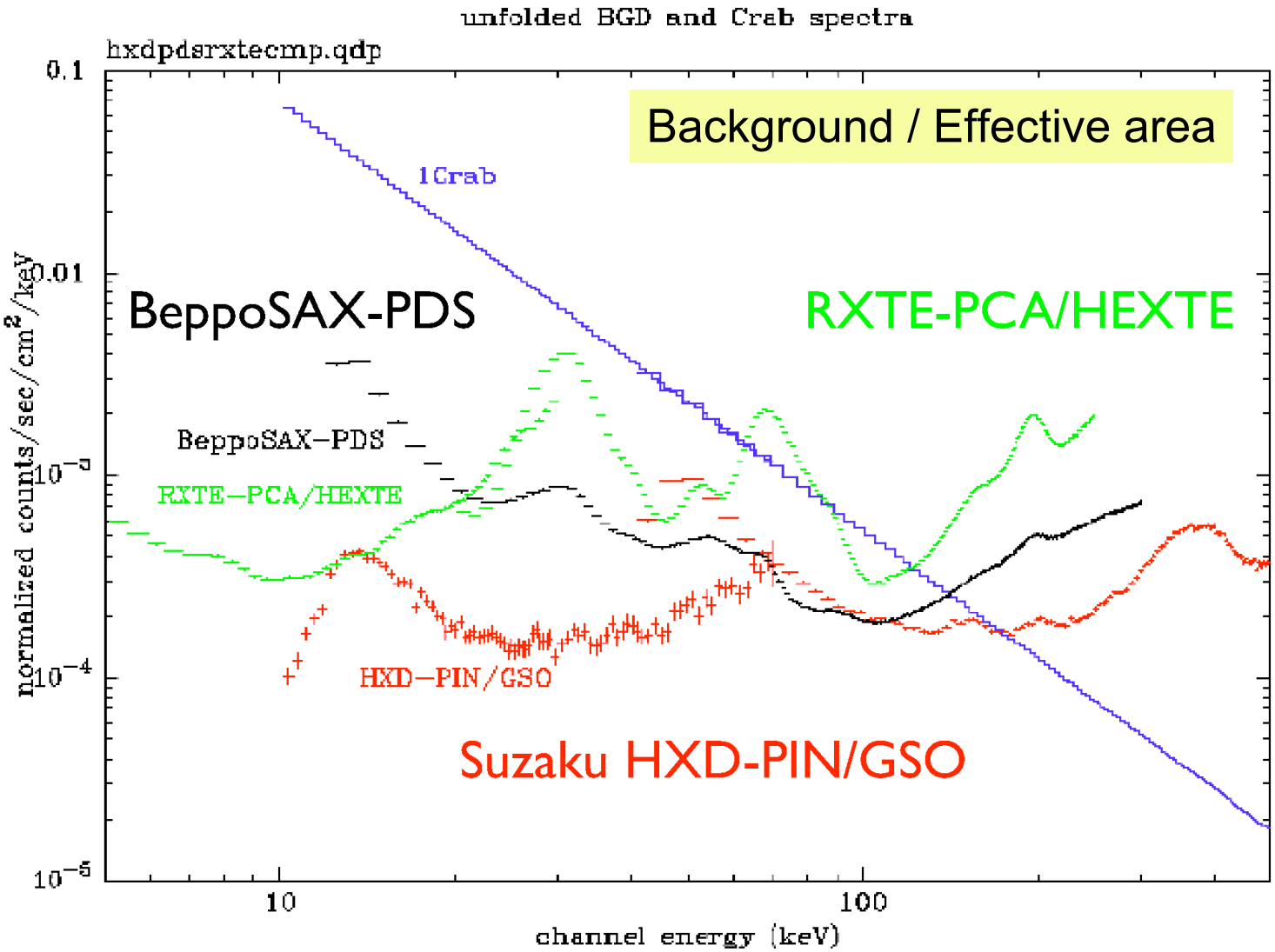
Structure of HXD



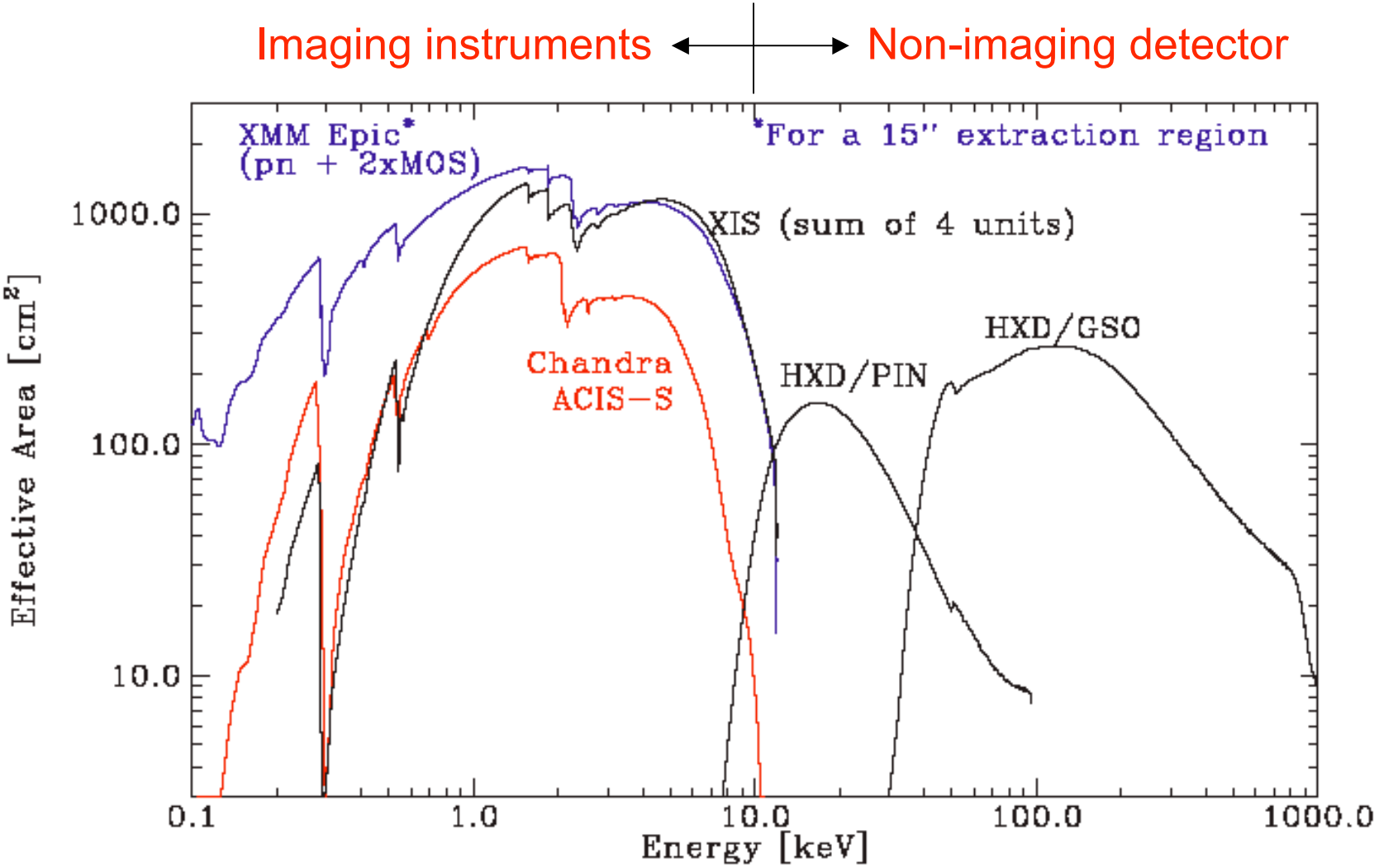
1 unit



Comparison of the background/sensitivity among Suzaku, Beppo-SAX, RXTE



Comparison of the effective area

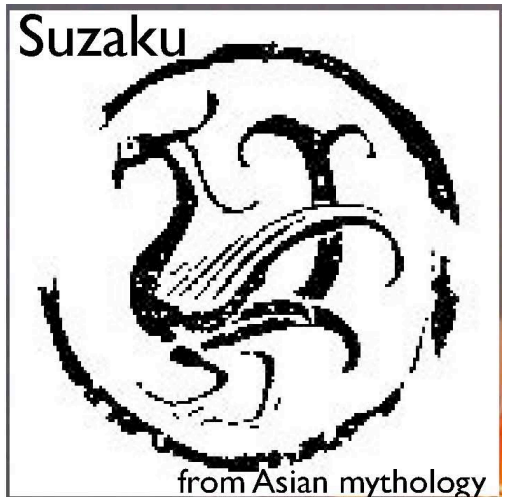


Launch of Suzaku

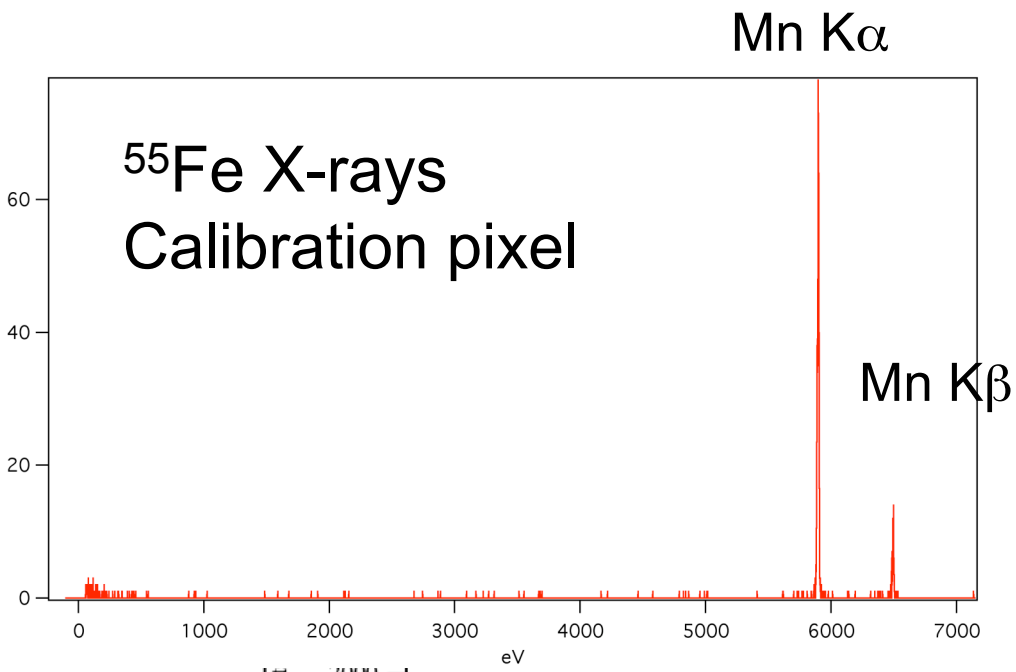
July 10, 2006 Uchinoura space center

Initial operations of Suzaku

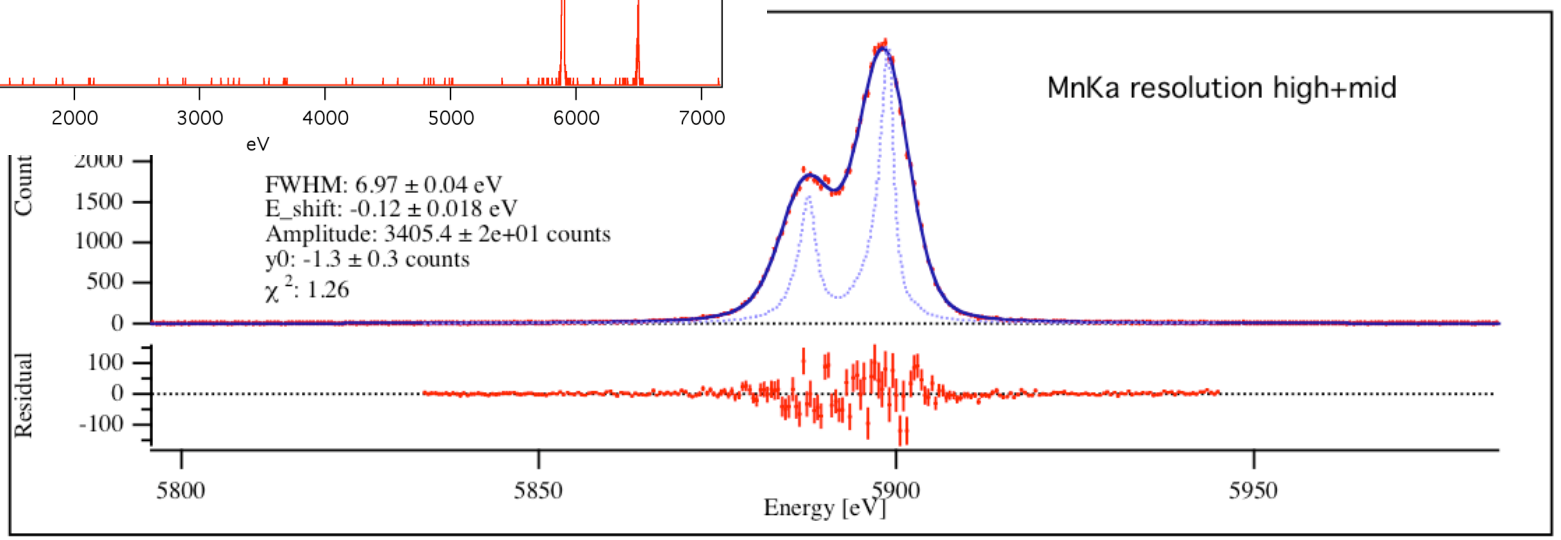
- July 10 — Successfully launched by M-V-6 rocket
  Named as Suzaku. One of 4 ancient Asian deities who guard the Universe.
- July 11 — 3-axis stabilized attitude.
- July 12 — Optical Bench extended.
- July 21 — Perigee-up maneuver finished.
- July 26 — XRS sensor reached 60 mK.
- Aug 5 — ΔE=7eV is achieved.
- Aug 8 — Liquid He lost; end of XRS.
- Aug 12-13 — First light with XIS
- Aug 17 — First light with HXD



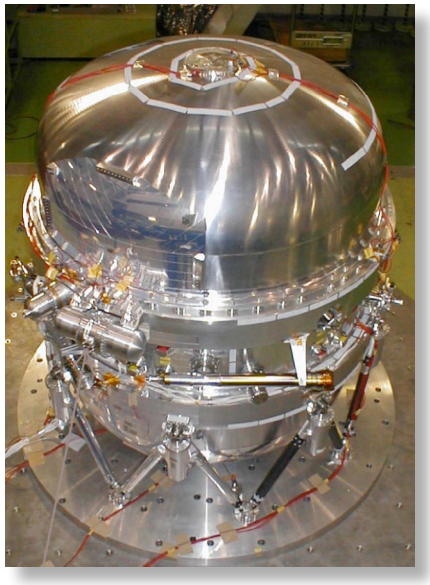
Flight performance of XRS



Energy resolution of 7 eV was confirmed using ^{55}Fe source.



Tragedy: Loss of XRS

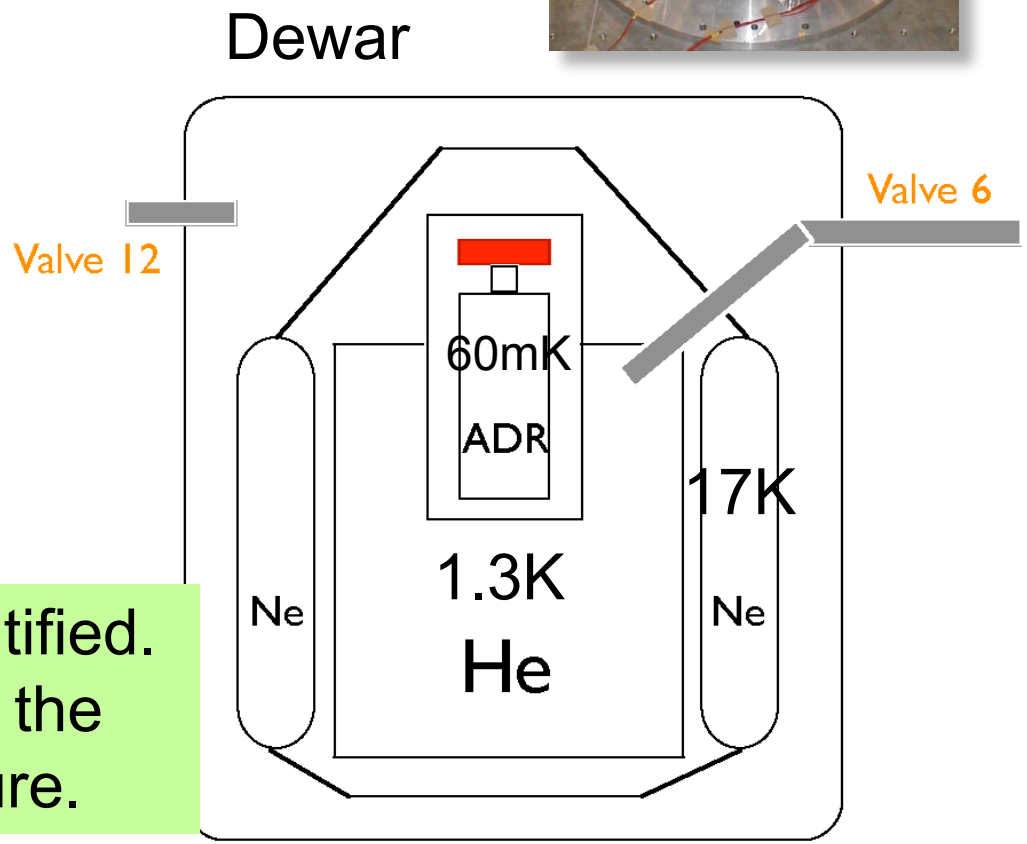


July 10 Valve 6 (He vent) was opened.

July 25 Valve 12 (main shell evacuation valve) was opened.

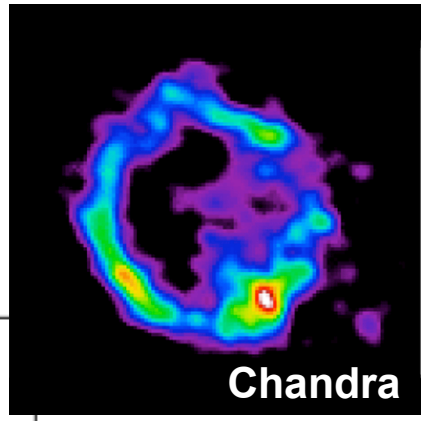
July 29 First temperature spikes were seen, indicating He gas got into the dewar vacuum space.

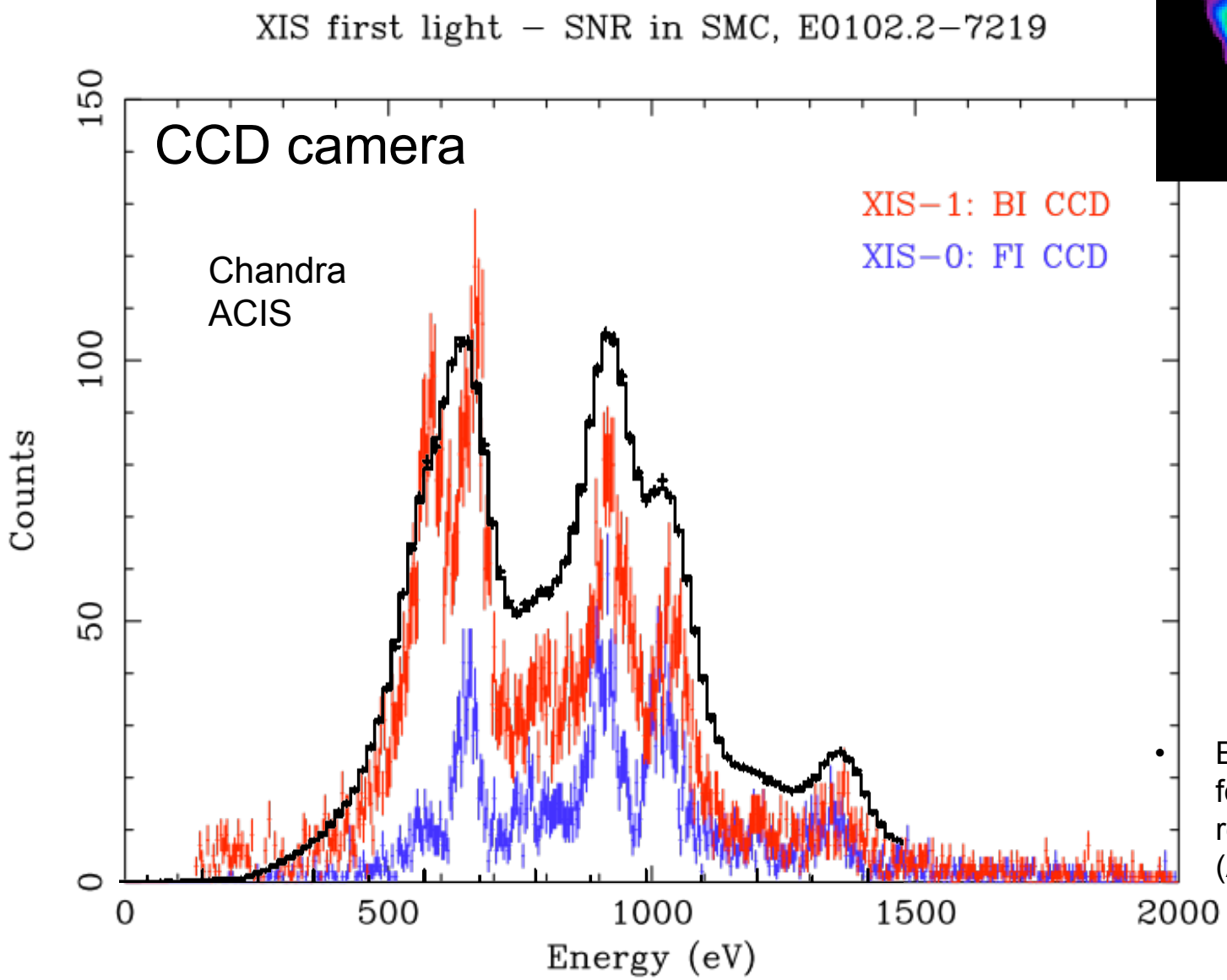
Aug 5 7 eV was achieved for most of the pixels.



Cause of the failure was identified. We will do our best to realize the calorimeter again in near future.

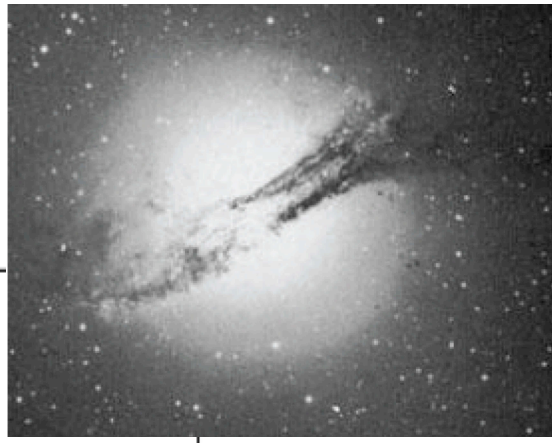
XIS first light: E0102-7219

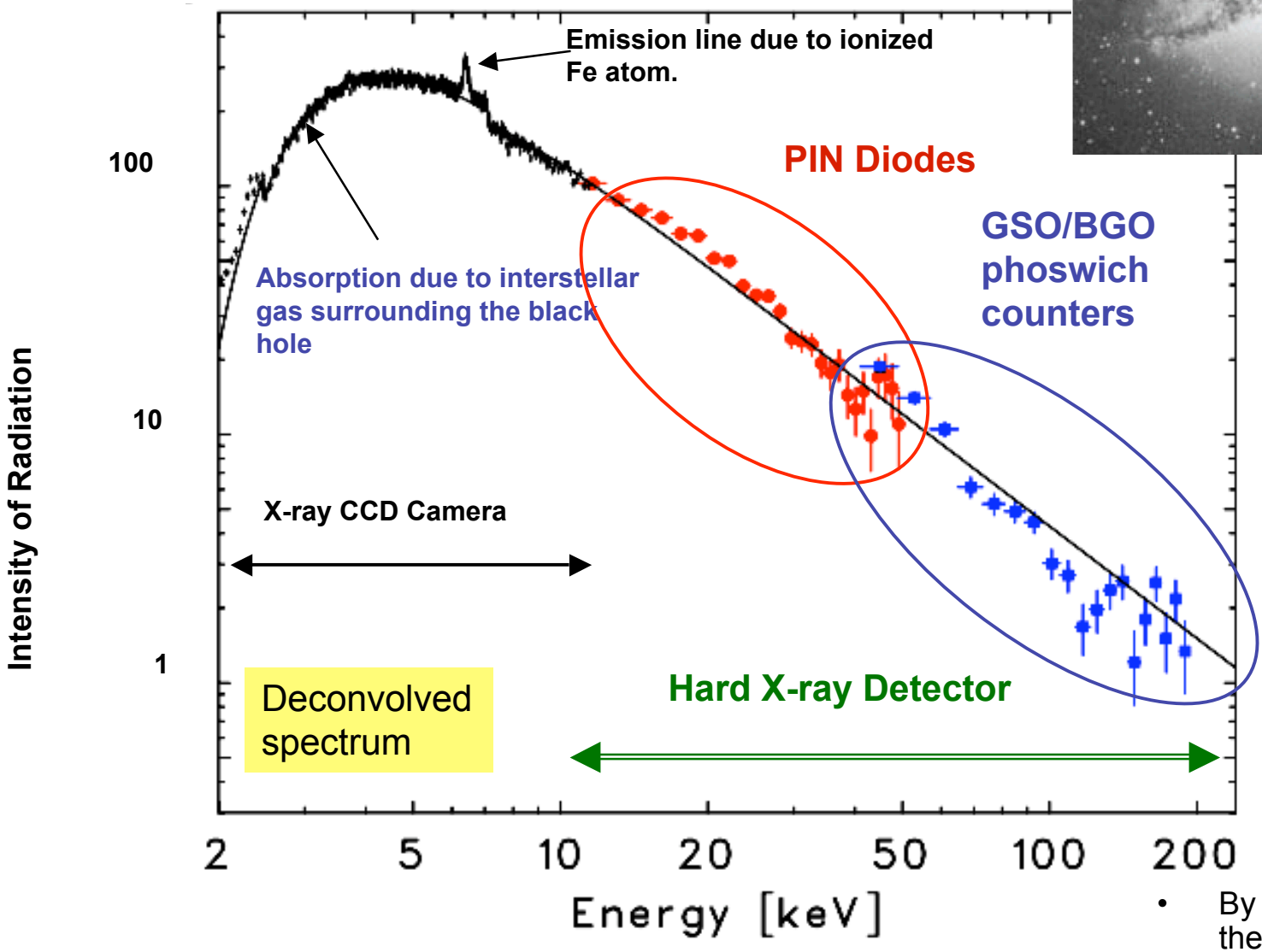




- By the XIS team for the press release (Aug/13/05)

HXD first light: Cen-A



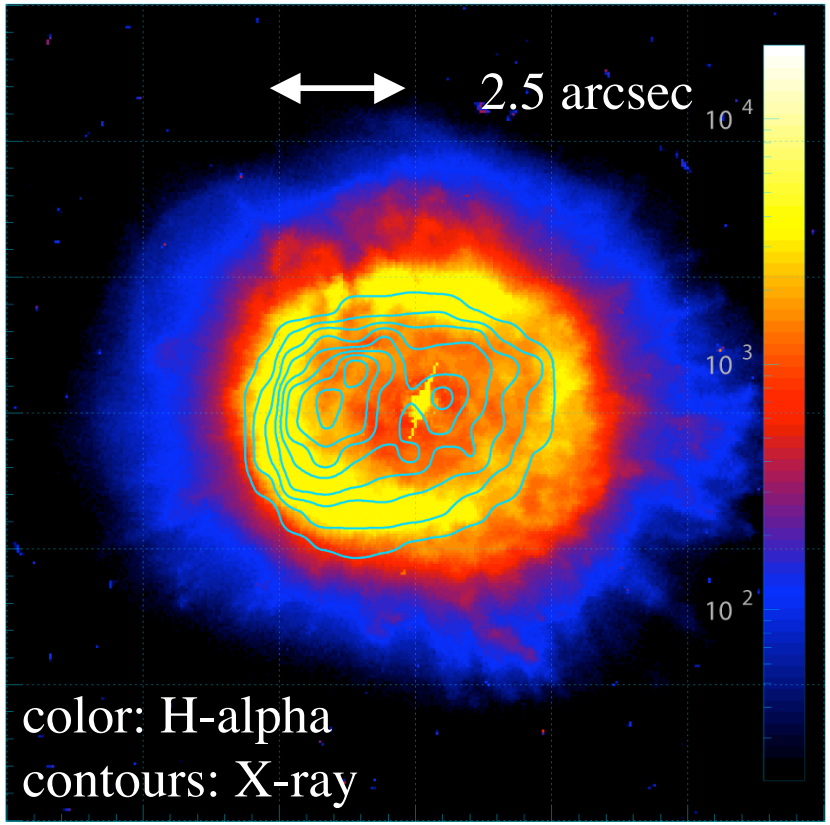


- By the HXD team for the press release

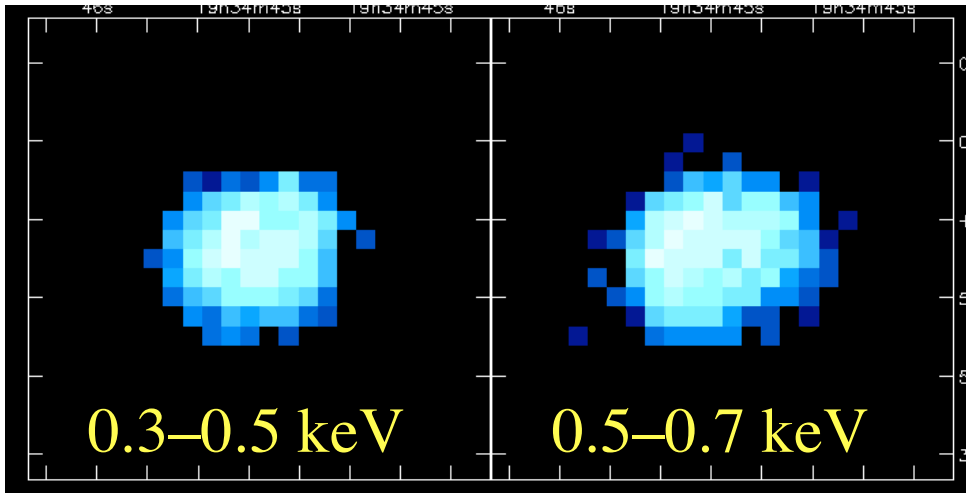
Planetary Nebulae

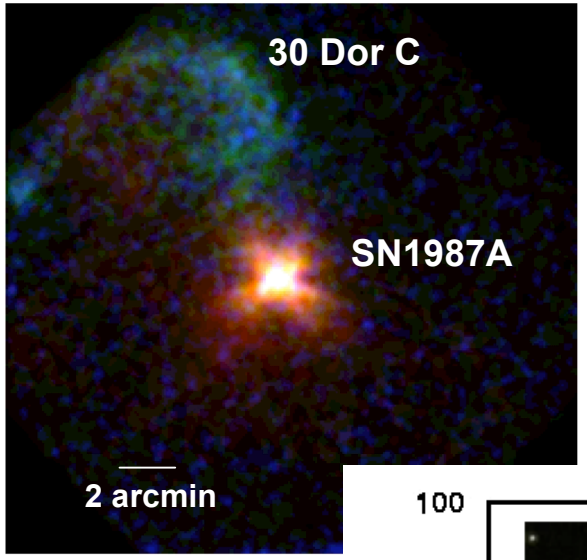
•Murashima, M. 2006, PhD thesis
•Murashima, M. et al. ApJL, to be submitted

- BD+30°3639 / HD184738 / V1966 Cyg
- One of the most well studied planetary nebulae (PNe)
- (α,δ)=(19 34 45.23, +30 30 58.9) ; (*l*,*b*)= (64.79, +5.02)
- Distance 1.3±0.2 kpc N_H ~ 1e21 cm^{-2}



- The X-ray brightest PN.
- X-rays are emitted from inside the optical shell.
- Similar shapes in C- and O-bands.



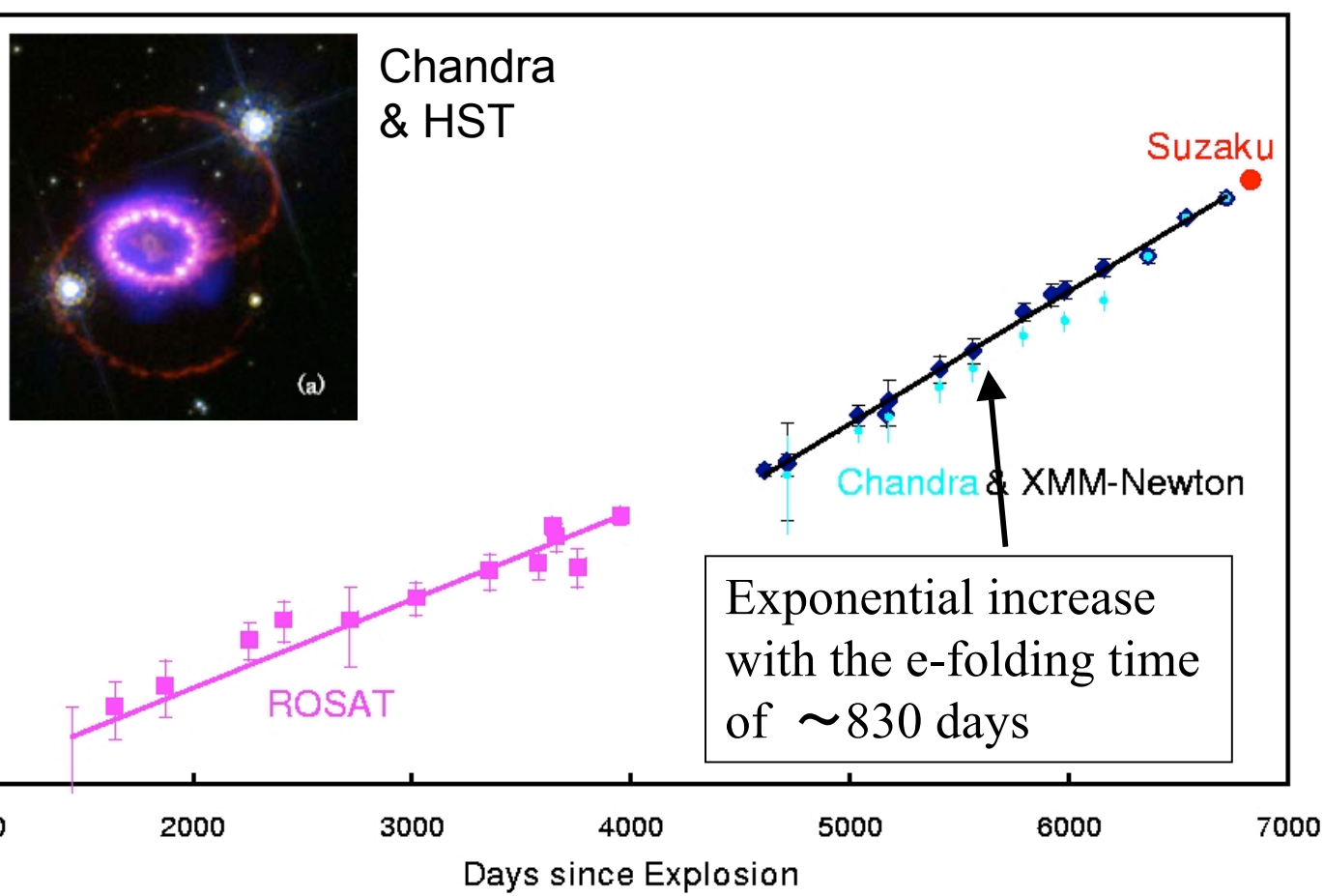


XIS image

SN1987A

Suzaku observations: 2005 Nov 3

Luminosity = 2.3E−13 erg/sec (0.5-2keV)



Preliminary, Suzaku team (Hasinger et al.)

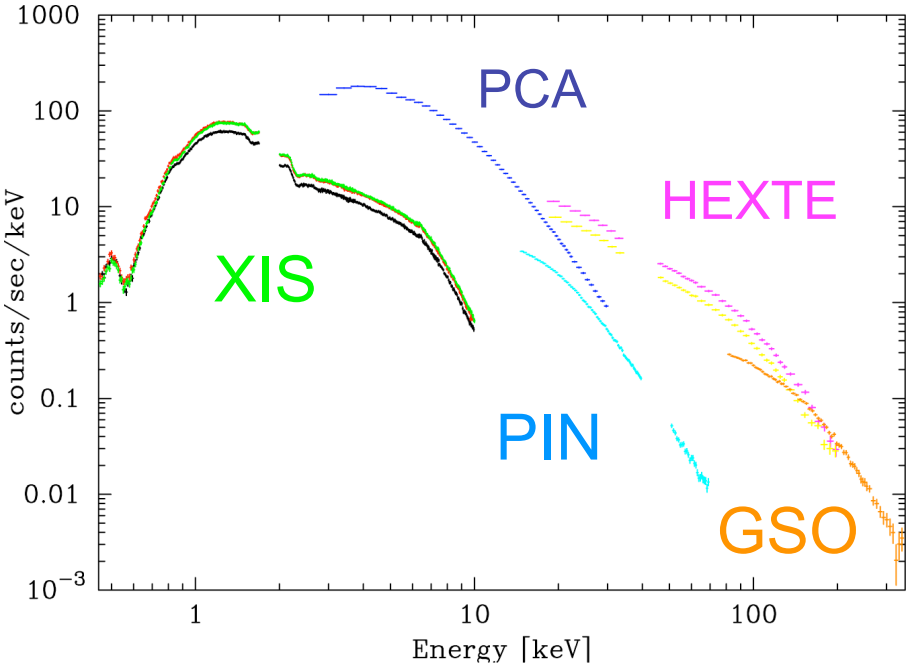
Wide-band spectrum of galactic BH: Cyg X-1

Observation: 2005 Oct 10, net exposure of 20 ks.
Simultaneous with RXTE

Diagnostics of the accretion disk ← simultaneous

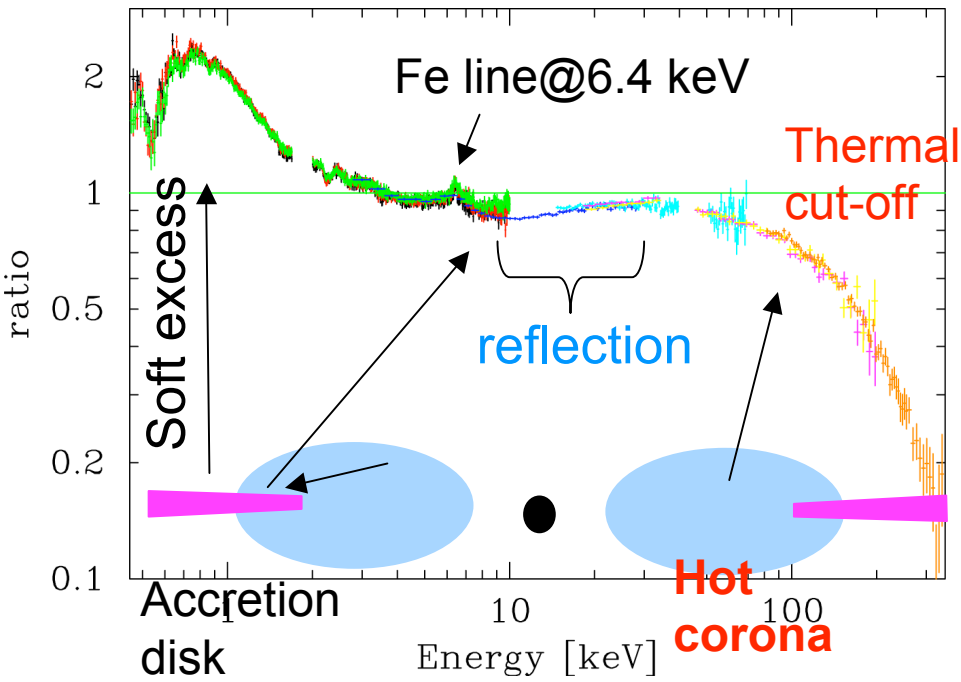
- Thermal emission from the disk
- Iron emission line
- Reflection feature

Cyg X-1: Low/Hard state



Preliminary, Suzaku team (Kubota et al.)

Ratio to a power-law model (Γ=1.6)

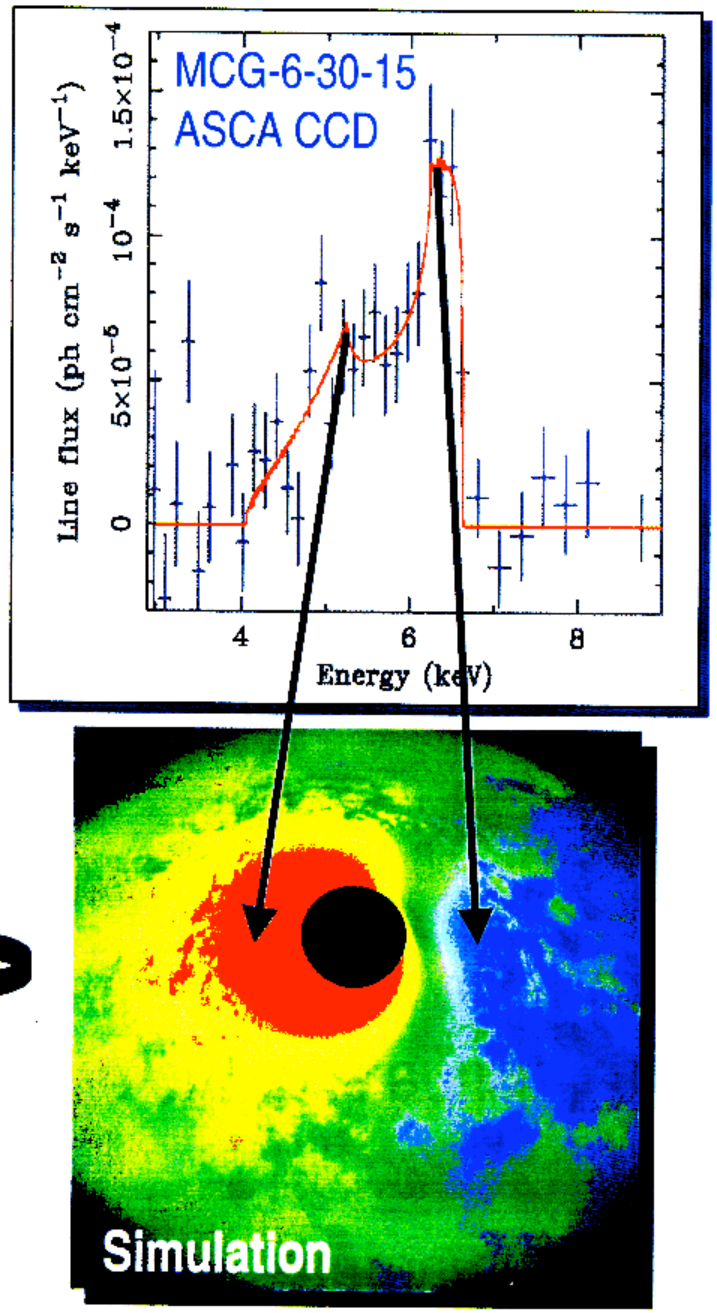


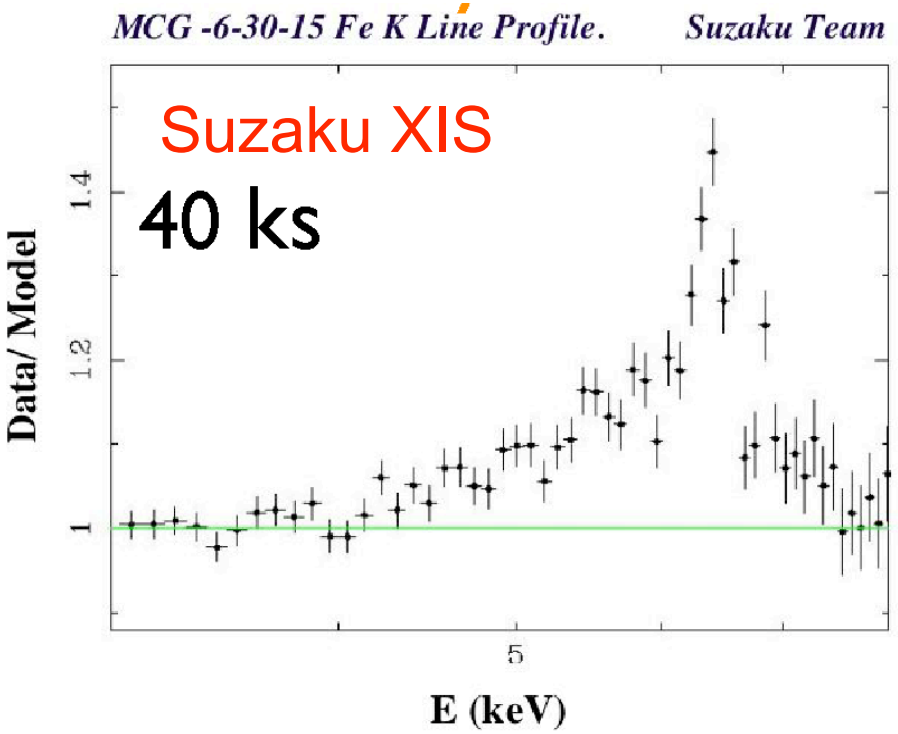
Disk line

First detection by ASCA

ASCA discovered a broad and skewed iron line from MCG-6-30-15 (Tanaka et al. 1995).

Key science in AGN





Summary: Suzaku strengths

Suzaku features	Science enhancements
Simultaneous broadband coverage (0.2-600 keV)	Resolving broad Fe K lines, constraining the high-energy continuum
Improved line-spread function at low energies	Measurements of spectral features of C, N, O, etc.
Low internal background	High sensitivity measurements of extended sources
Higher counting rate capability	Improved spectro-photometry of X-ray binaries

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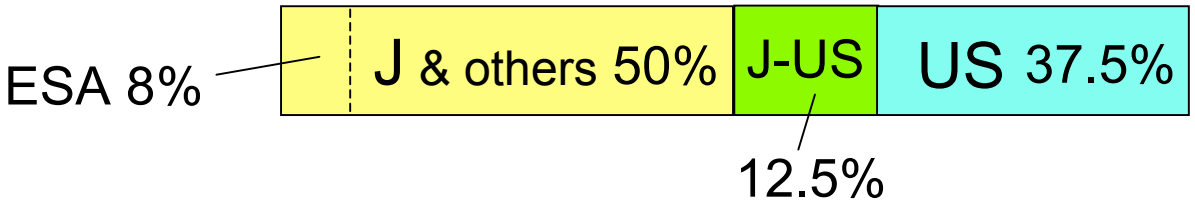
Scientific results Special issue of PASJ, late 2006

Suzaku AO

AO1 2006 April 1 - 2007 March 31



Observatory: 4%
Calibration : 3%
DDT : 5%

AO2 2007 April 1 - 2008 March 31

Announcement of AO2: 2006 summer

Due date for proposal submission: 2006 Dec. 1